Increase of energy efficiency of energy generation due to utilization of waste heat on district heating systems of villages Shapkino and Podtesovo of the North of Krasnoyarsk region

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Abstract: The relevance of the work is due to the implementation of the Federal law "on energy saving and energy efficiency and on amendments to certain legislative acts of the Russian Federation" and is aimed at reducing the cost of production of electricity and heat in the Northern regions of the Krasnoyarsk territory.
The aim: Improving energy efficiency of thermal energy production through the modernization of coal-fired boilers, the rationale for the choice of an alternative technology to convert thermal energy into electricity in the areas of decentralized energy. The creation of plants competing with DES for generation of thermal and electric energy, increasing the economic efficiency of energy production in DHS-3 and DHS-22 villages Shapkino and Podtesovo.
Research methods: Analysis of existing technologies for utilization of low-potential thermal energy in the energy sector; Thermal, technical and economic analysis of technologies that allow converting low potential thermal energy into electrical energy; Simulation of installation parameters based on the organic Rankine cycle using the Smoweb software package; Analysis of modern manufacturers of organic Rankine cycle technology in order to select the most suitable
Results: a comparative analysis of existing technologies for utilization of low-potential heat energy was carried out and the most effective option for energy efficiency was chosen. Was heat produced and techno-economic analysis of the application of technologies to convert low-grade thermal energy into electrical energy; modeling installation working on the principle of organic Rankine cycle utilizing heat energy from the district heating systems of villages Shapkino and Podtesovo.

1. Choice of heat recovery technology

It is no secret that at present the tariff for thermal and electric energy in the far North reaches more than 30 rubles / kWh [1]. This is due to the existing method of generation, and the lack of local production of solid fuel and as a consequence of its delivery over long distances. One of the options for reducing tariffs is the transition to Autonomous coal-fired boilers for large settlements and the development of renewable energy.

The population in many villages of the Far North is not growing, so housing construction is mainly of a replacement nature. Increased requirements for the construction of new buildings can only have a very limited effect, and emphasis must be placed on the overhaul of the existing stock of buildings.

Installed heat meters for consumers is quite small or not at all. Therefore, both indicators of heat production and indicators of its consumption are mainly calculated values, and calculations for heat energy are still carried out according to the standards, and not for real consumption.

In programs for boosting energy efficiency projects for upgrading boilers, laying of heat networks with prednisolone pipes, installation ETC in apartment buildings and buildings of social sphere, on warming of houses, equipping house-to-apartment metering devices. An important measure is to optimize housing (decommissioning partially inhabited houses with relocation of people preparing for and carrying out capital repair of housing for resettlement in existing houses).

Improving energy efficiency in the Northern environment is often not a task to reduce consumption, but to eliminate its deficit. At the expense of measures on increase of efficiency of use of energy and reduction of losses you can completely cover the shortage of the supply of energy to end consumers.

High energy intensity hinders the development of the economy of the Far North and the possibility of forming their own tax revenues. Policies to improve energy efficiency in the Northern regions has been implemented slowly and has brought very limited benefits, and additional energy demand in many regions was determined not only by the GRP, but also increase its energy consumption. Currently, the widely distributed four technologies to obtain from low-grade heat energy electric:

- Stirling engine
- Organic Rankine cycle
- Rankine Microcycle
- Thermoelectric converter

As noted in [2] (figure 1) Stirling Engine has a high efficiency and has found its application in industrial samples at temperatures 650-800 and above, but this source of heat network water 95 is not applicable. The Rankine microcycle is effective only in the joint production of heat and electricity, which is not required for this task. Thermoelectric converters have low efficiency below 5%.

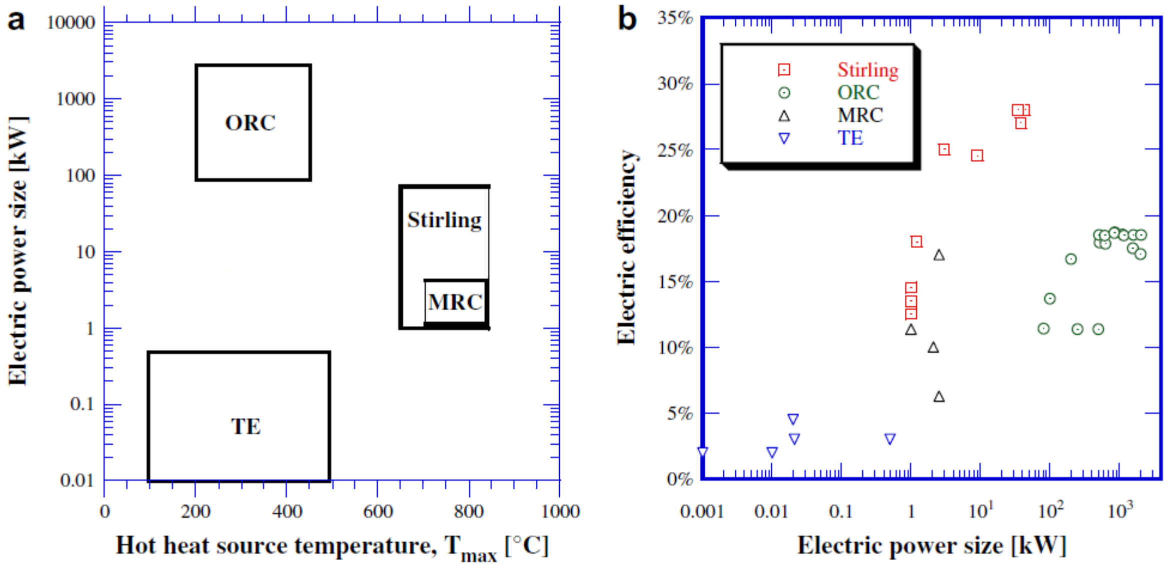

Figure 1. Analysis of technologies for converting thermal energy into electrical energy low power

As shown in the figure and by the authors [3-8] for the utilization of low-potential thermal energy, the most suitable and Mature technology is the organic Rankine cycle.

2. Inclusion of the installation of organic Rankine cycle in the technological scheme

Recycling the cooling exhaust gases to a temperature below the dew point temperature is called deep. There are two types of ORC installations, the classical Rankine cycle and the regenerative one with the addition of a heat exchanger transferring heat from steam after the turbine to the condensate after the condenser. Given the above, there are four options for including the ORC installation for heat recovery of exhaust gases from the boiler and two options for including the ORC installation that converts low potential thermal energy from hot water into electric:

- Deep utilization with ORC without regeneration
- Deep utilization with regenerative ORC
- Utilization with ORC without regeneration
- Utilization with regenerative ORC
- Conversion of thermal energy of mains water into electric ORC without regeneration
- Conversion of thermal energy of mains water into electrical energy with regenerative ORC

3. Assessment of the technical and economic effect of the implementation of recycling

The valuation of the main equipment is divided into:

- Assessment of the cost of heat exchanger utilization (gas-Air steel or gas-water glass))
- Evaluation of the cost of the heater (Air-water steel in the schemes with the utilization of the heat of gases to a temperature above the dew point)
- Estimate cost of installation of the ORC with screw expander

Assessment of the cost of heat exchangers was taken from the online calculator of the cost of heat exchangers with a dollar exchange rate relevant for 2014.
Estimation of the cost of the ORC module was taken from the price list of the company “infinity turbine Ukraine”. The estimation of specific investments was carried out with the help of regressive analysis of cost, $ / kW :

$$K_{\text{ОЦР}} = 1338 \cdot P + 15474{,}18$$

Technical and economic analysis of the implementation of the CRO on the district heating systems in the village of Shapkino presented in table 1 and 2, in the village of podtesovo in tables 3 and 4

Table 1. – The main technical and economic indicators of utilization heat of the leaving gases from the boiler of conversion of the district heating systems of village Shapkino

Parameter	Utilization with ORC without regeneration	Utilization with regenerative ORC	Deep utilization with ORC without regeneration	Deep utilization with regenerative ORC
Gas temperature, °C	200	200	200	200
The temperature of the cooled gases, °C	120	120	80	80
Heat recovery, kW	300	300	345	345
Efficiency of ORC,%	10,0006	10,3573	10,0006	10,3573
ORC electric power,kW	28,8137	29,8415	33,1358	34,3177
The R142b flow rate, kg/s	1,137	1,178	1,335	1,382
The cost of the ORC, $	54029	55405	59813,2	61394,7
The price of the heat exchanger utilization, $	48100	48100	168700	168700
The price of the heater, $	20000	20000		
Capital investments, mln.	3,664	3,705	6,855	6,902

RUB.				
Operating Costs, mln. RUB. / year	5,532	5,532	6,171	6,180
Cost of energy production, RUB/(kW·h)	27,029	26,137	26,21	25,351
Income of electricity mln. RUB. / year	3,619	3,937	4,353	4,719
Payback period, years	2	1	2	2
Savings, t.t./year	71,642	74,198	82,388	85,327

Table 2. – The main technical and economic indicators of of heat conversion of the district heating systems of village Shapkino

Parameter	Conversion of thermal energy of mains water into electric ORC without regeneration	Conversion of thermal energy of mains water into electrical energy with regenerative ORC
Water inlet temperature, °C	120	120
Water temperature output, °C	70	70
Excess heat power, kW	1929	1929
Efficiency of ORC,%	10,0006	10,3573
ORC electric power,kW	189,053	195,796
The R142b flow rate, kg/s	7,465	7,731
The cost of the ORC, $	268446	277469
Capital investments, mln. RUB.	8,053	8,324
Operating Costs, mln. RUB. / year	27,129	27,183
Cost of energy production, RUB/(kW·h)	20,19	19,54
Income of electricity mln. RUB. / year	32,917	35,005
Payback period, years	1	1

Table 3. – The main technical and economic indicators of utilization heat of the leaving gases from the boiler of conversion of the district heating systems of village Podtesovo

Parameter	Utilization with ORC without regeneration	Utilization with regenerative ORC	Deep utilization with ORC without regeneration	Deep utilization with regenerative ORC
Gas temperature, °C	160	160	160	160
The temperature of the cooled gases, °C	120	120	80	80
Heat recovery, kW	1150	1150	1400	1400
Efficiency of ORC,%	0,100006	0,103573	0,100006	0,103573
ORC electric power,kW	110,453	114,392	134,464	139,26
The R142b flow rate, kg/s	4,450	4,609	5,418	5,611
The cost of the ORC, $	163271	168542	195400	201818
The price of the heat exchanger utilization, $	483000	483000	960700	960700
The price of the heater, $	264400	264400		

Capital investments, mln. RUB.	27,320	27,478	34,683	35,451
Operating Costs, mln. RUB. / year	15,064	15,096	11,736	11,775
Cost of energy production, RUB/(kW·h)	19,20	18,57	12,28	11,90
Income of electricity mln. RUB. / year	20,018	21,237	30,972	32,456
Payback period, years	2	2	2	2
Savings, t.t./year	274,630	284,424	334,331	346,256

Table 4. – The main technical and economic indicators of of heat conversion of the district heating systems of village Podtesovo

Показатель	Преобразование с ОЦР без регенерации	Преобразование с регенеративным ОЦР
Water inlet temperature, °C	120	120
Water temperature output, °C	70	70
Excess heat power, kW	24184	24184
Efficiency of ORC,%	0,100006	0,103573
ORC electric power,kW	2322,77	2405,62
The R142b flow rate, kg/s	93,588	96,926
The cost of the ORC, $	3123573	3234434
Capital investments, mln. RUB.	93,707	97,033
Operating Costs, mln. RUB. / year	337,652	338,317
Cost of energy production, RUB/(kW·h)	20,46	19,79
Income of electricity mln. RUB. / year	400,105	425,755
Payback period, years	1	1

Result:

- Deep utilization allows you to remove more heat from the exhaust gases due to condensation of water vapor, but at the same time in the outgoing gases contain sulfur oxides which, when condensed, react with water to form sulfuric acid, which leads to sulfuric acid corrosion. This problem can be solved by using a glass heat exchanger. This lack of devoid of scheme with gas-air utilization.
- The addition of a regenerative heat exchanger increases the cost of installation, but allows to increase the efficiency of the ORC by reducing heat losses in the condenser. The efficiency of the regenerative heat exchanger depends on the freon used and the efficiency of the turbine.
- The inclusion of an ORC using mains water as a heat source allows the production of electrical energy from heat. With this inclusion, the coefficient of use of thermal turbines increases, and as a result, the cost of production of electric energy is reduced, the reliability of operation is improved. The supply to the ORC as a source of heat of the heating steam selection will increase the degree of overheating of freon and efficiency, but will entail an increase in capital costs for individual heat exchangers and a system for regulating the distribution of steam between the network heaters and the ORC.
- As can be seen from tables 1-4, the option with deep utilization and regenerative ORC was preferred, but the most profitable option is the conversion of excess thermal energy into electrical energy. This is due to the fact that the costs include only the cost of fuel to produce this energy, since it is the difference between the installed heat capacity and the nominal

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